GROUP ON
EARTH OBSERVATIONS

CRITICAL EARTH OBSERVATION PRIORITIES

GEO TASK US-09-01a

Energy Societal Benefit Area

Revised Report to the
GEO User Interface Committee

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Group on Earth Observations

GEO Task US-09-01a:
Critical Earth Observation Priorities for Energy SBA

Advisory Group Members & Analyst

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Group on Earth Observations

GEO Task US-09-01a:
Critical Earth Observation Priorities for Energy SBA

Summary

This report is part of GEO Task US-09-01a, with the objective of identifying critical Earth observation priorities for nine Societal Benefit Areas (SBAs). This document discusses the Energy SBA, focusing on the renewable energy sub-areas of hydropower, land-based wind power, offshore wind power, bioenergy, solar power, and geothermal power. In this effort, the Analyst enlisted the help of 14 expert advisory group members from a wide geographic distribution, including at least one member from every continent except Antarctica. Sixty-one (61) publicly available documents, reports, and websites were located and analyzed, with 47 of them ultimately included because they contained information relevant to the analysis. The Analyst located the documents through literature searches and through the Advisory Group members. These documents were analyzed by searching through them for references to desired Earth observations as well as information about the adequacy of current Earth observations.

The identified observations/parameters were initially arranged in two ways: those which are likely to benefit many of the sub-areas of renewable energy (cross-cutting parameters) and those which are high priority within each sub-area of renewable energy. These two lists were reconciled by using projections of the future importance of each energy type to prioritize the cross-cutting parameters that benefited the highest ranked (likely to generate the most energy by 2030) energy types. In this final step of the prioritization, the following four tiers were developed, with those cross-cutting parameters which benefitted the largest projected renewable energy types in the first three tiers, down to parameters which were not cross-cutting in the last tier:

Tier 1: Precipitation, elevation / topography
Tier 2: Wind speed, wind direction, land cover
Tier 3: Relative humidity, air temperature, surface temperature
Tier 4: Other parameters requested, but which are not cross-cutting.

See Section 5.2 for more details on these parameters.

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1. Introduction

This report articulates Earth observation priorities for the Energy SBA, based on an analysis of 61 publicly-available documents produced by Group on Earth Observations' Member Countries and Participating Organizations.

1.1. GEO and Societal Benefit Areas

The Group on Earth Observations (GEO)[1] is an intergovernmental organization working to improve the availability, access, and use of Earth observations to benefit society. GEO is coordinating efforts to build a Global Earth Observation System of Systems (GEOSS)[2]. GEOSS builds on national, regional, and international observation systems to provide coordinated Earth observations from thousands of ground, in situ, airborne, and space-based instruments.

GEO is focused on enhancing the development and use of Earth observations in nine SBAs:

Agriculture	Biodiversity	Climate
Disasters	Ecosystems	Energy
Human Health	Water	Weather.

1.2. Task US-09-01a

The objective of GEO Task US-09-01a is to establish and conduct a process to identify critical Earth observation priorities within each SBA and those common to the nine SBAs. Many countries and organizations have written reports, held workshops, sponsored projects, conducted surveys, and produced documents that specify Earth observation needs. Task US-09-01a focuses on compiling information on observation parameters from a representative sampling of these existing materials and analyzing across the materials to determine the priority observations.

This task considers includes ground, in situ, airborne, and space-based observations. The task includes both observed and derived parameters as well as model products. This task seeks to identify Earth observation needs across a full spectrum of user types and communities in each SBA, including observation needs from all geographic regions and significant representation from developing countries.

GEO will use the Earth observation priorities resulting from this task to determine, prioritize, and communicate gaps in current and future Earth observations. GEO Member Countries and Participating Organizations can use the results in determining priority investment opportunities for Earth observations.

[1] GEO Website: *http:// www.earthobservations.org*
[2] GEO 10-Year Implementation Plan: *http://www.earthobservations.org/documents.shtml*

1.3. Purpose of Report

The primary purpose of this report is to articulate the critical Earth observation priorities for the Energy SBA. The intent of the report is to describe the overall process and specific methodologies used to identify documents, analyze them, and determine a set of Earth observation parameters and characteristics. The report describes the prioritization methodologies used to determine the priority Earth observations for this SBA. The report also provides information on key challenges faced, feedback on the process, and recommendations for process improvements.

The primary audience for this report is the GEO User Interface Committee (UIC), which is managing Task US-09-01a for GEO. The GEO UIC will use the results of this report in combination with reports from the other eight SBAs. The GEO UIC will perform a meta-analysis across all nine SBA reports to identify critical Earth observation priorities common to many of the SBAs. Based on the nine SBA reports, the GEO UIC will produce an overall Task US-09-01a report, including the common observations and recommendations for GEO processes to determine Earth observation priorities in the future.

The report's authors anticipate that the GEO Secretariat, Committees, Member Countries, Participating Organizations, Observers, Communities of Practice, and the communities associated with the Energy SBA are additional audiences for this report.

1.4. Scope of Report

This report addresses the Earth observation priorities for the Energy SBA. In particular, this report addressed the sub-area of renewable energy, including hydropower, land-based wind, offshore wind, solar, bioenergy, and geothermal power within the Energy SBA (see Section 3 for more details).

The report provides some background and contextual information about the Energy SBA. However, this report is not intended as a handbook or primer on the Energy SBA, and a complete description of the Energy SBA is beyond the scope of this report. Please consult the GEO website (referenced above) for more information about the Energy SBA.

The report focuses on the Earth observations within the Energy SBA, independent of any specific technology or collection method. Thus, the report addresses the "demand" side of observation needs and priorities. The report does not address the specific source of the observations or the sensor technology involved with producing the observations. Similarly, any discussions of visualization tools, decision support tools, or system processing characteristics (e.g., data format, data outlet) associated with the direct use of the observations are beyond the scope of this report.

In this report, the term "Earth observation" refers to parameters and variables (e.g., physical, geophysical, chemical, biological) sensed or measured, derived parameters and products, and related parameters from model outputs. The term "Earth observation priorities" refers to the parameters deemed of higher significance than others for the given SBA, as determined through the methodologies described within. The report uses the terms "user needs" and "user

requirements" interchangeably to refer to Earth observations that are articulated and desired by the groups and users in the cited documents. The term "requirements" is used generally in the report to reflect users' wants and needs; the use in this report does not imply technical, engineering specifications.

Following this introduction, the report discusses the overall approach and methodologies used in this analysis (Section 2). Section 3 describes the Energy SBA and the specific sub-areas that were part of the analysis. Section 4 articulates the specific Earth observations for each Energy sub-area, and Section 5 presents the priority observations across the Energy SBA. Sections 6 and 7 present additional findings from the analysis of the documents and any recommendations. The appendices include the documents cited and consulted as well as a list of acronyms used throughout the document.

2. Methodology and Process

2.1. Task Process

The basic methodology for identifying critical Earth observation priorities within an SBA relies on an Analyst working in coordination with an Advisory Group to select the scope of the analysis, identify and analyze relevant documents, and finally extract and prioritize relevant Earth observation parameters. The GEO UIC established a general process for each of the SBA Analysts to follow in order to ensure some consistency across the SBAs. This general process for each SBA involves nine (9) steps, as summarized in the following list:

- Step 1: UIC Members identify Advisory Groups and Analysts for each SBA
- Step 2: Determine scope of topics for the current priority-setting activity
- Step 3: Identify existing documents regarding observation priorities for the SBA
- Step 4: Develop analytic methods and priority-setting criteria
- Step 5: Review and analyze documents for priority Earth observations needs
- Step 6: Combine the information and develop a preliminary report on the priorities
- Step 7: Gather feedback on the preliminary report
- Step 8: Perform any additional analysis
- Step 9: Complete the report on Earth observations for the SBA.

A detailed description of the general US-09-01a process is available at the Task website *http://sbageotask.larc.nasa.gov* or the GEO website. For the Energy SBA analysis, many of these steps were conducted simultaneously. The Analyst identified existing documents (Step 3) concurrently with development of the analytic methods and priority-setting criteria (Step 4), in coordination with the Advisory Group. This allowed the methods to be tailored to the types of documents that were being identified. Also, as input was received from the Advisory Group, the Analyst continued to conduct Step 3 (document identification and analysis) iteratively throughout the process, as Advisory Group members continued to identify relevant documents.

2.2. Analyst and Advisory Group

The Energy SBA had an "Analyst" and an "Advisory Group" to conduct the process of identifying documents, analyzing them, and prioritizing the Earth observations. The Analyst served as the main coordinator to manage the activities.

2.2.1. Analyst

For the Energy SBA, the Analyst was Erica Zell. She holds a master's degree in Environmental Engineering, and has twelve years of experience in environmental research, including significant international experience. She has been working at Battelle for five years, currently serving as an Environmental Research Scientist. She specializes in the application of satellite data for energy applications, the impacts of electric power generation, and distributed and renewable energy technologies. She also has project management experience and has managed the production of several technical reports.

The Energy SBA Analyst served through the Battelle Memorial Institute under contract to the National Aeronautics and Space Administration (NASA).

2.2.2. Advisory Group

The Analyst assembled the Advisory Group, which consisted of 14 scientific and technical experts, recognized as credible and respected in the field of renewable energy or some subset thereof (e.g., solar energy). The Advisory Group members are from both developed and developing countries, and encompass all regions of the world, representing GEO Countries and Participating Organizations, as listed in Table 1.

The Analyst developed the pool of candidates for the Advisory Group based on contacts provided by the Energy Community of Practice (COP) and identification of participants in relevant workshops and conferences. The Analyst invited each potential candidate to participate and provided each with information on the expectations for Advisory Group members. The role of the Advisory Group was to help identify relevant documents, comment on the analytic methods and priority-setting criteria utilized, and review the Analyst's findings, priorities, and reports. Communication was conducted primarily by a combination of emails and group teleconferences.

2.3. Methodology

2.3.1. Documents

Task US-09-01a methodology required examination of a wide range of sources for potentially relevant, publicly available documents, including:

- International, regional, and national documents focused on data sources, applications, or research priorities
- Project reports (e.g., findings from major regional/national projects)
- Surveys (e.g., of users of solar resource data)
- Workshop and conference summaries
- Individual peer-reviewed journal articles.

Table 1. Advisory Group for Energy SBA.

Name	GEO Country or Organization	Affiliation	Geographic Region	Area of Expertise/ Specialty
Charlotte Bay Hasager	Denmark	Risoe National Laboratory, Technical University of Denmark	Europe	Wind
Amit Kumar	India	The Energy and Resources Institute (TERI)	Asia/Middle East	Broad renewable energy
Ellsworth LeDrew	Canada	University of Waterloo	North America	Chair of GEOSS Energy COP
Maxwell Mapako	South Africa	Natural Resource and Environment, CSIR	Africa	Broad renewable energy
Pierre-Philippe Mathieu	European Space Agency	European Space Agency	Europe	Broad renewable energy
Richard Meyer	Germany	EPURON GmbH	Europe	Solar
Monica Oliphant	Australia	International Solar Energy Society	Oceania/Australia	Solar
Enio Pereira	Brazil	INPE (Brazilian National Agency for Space Research)	South/Central America	Broad renewable energy
Thierry Ranchin	France	Ecole des Mines de Paris and Co-Chair of the GEO Energy Community of Practice	Europe	Broad renewable energy
David Renne	United States	Department of Energy, National Renewable Energy Laboratory	North America	Solar and wind
Scott Sklar	United States	Stella Group	North America	Broad renewable energy
Gerry Sehlke	United States	Department of Energy, Idaho National Laboratory	North America	Hydropower
Han Wensink	The Netherlands	ARGOSS	Europe	Ocean
Gu Xingfa	China	Institute of Remote Sensing Applications	East Asia	Broad renewable energy

The Analyst used a twofold methodology for identifying potentially relevant documents: (1) literature and online searches, and (2) requests for Advisory Group members to suggest documents. The online searches conducted by the Analyst focused on the websites of international, regional, and national organizations engaged in renewable energy. The literature searches relied on standard library search tools using a variety of renewable energy key words. This twofold approach was used to ensure that the set of documents ultimately analyzed would have broad geographic distribution and represent both developed and developing countries. The Analyst emphasized to Advisory Group members that any documents suggested for analysis need to be publicly available. This resulted in an initial set of potentially relevant documents.

Upon further examination by the Analyst, each document had to include one of the following for consideration in the analysis: (1) specification of Earth observation parameters *needed by users* for renewable energy applications, or (2) reference to Earth observation parameters *currently in use* for renewable energy applications, with some indication of the *adequacy* of the parameter characteristics as currently available. While the Analyst focused initially on identifying the first type of document (identifying parameters needed by users), only a few of the identified documents fit neatly within this category. Thus, it was necessary to include the second type of document (focused on the adequacy of current observations) in order to have a broad enough set of documents from which priorities could be derived.

A certain degree of specificity was required for a document to be deemed relevant for analysis. That is, the document had to name the specific parameter(s) required or used, along with at least some indication of parameter characteristics (e.g., spatial resolution), in order to be included in the analysis. The parameter characteristics that were sought are as follows:

- Coverage/Extent
- Temporal resolution (frequency)
- Spatial resolution (vertical and horizontal, as relevant)
- Timeliness (availability of measurement)
- Accuracy/Precision.

2.3.2. Analytic Methods

For those documents that met the criteria described in Section 2.3.1, the Analyst first categorized the documents by renewable energy type(s) and region(s) represented (or global/international, if no specific geographic focus was noted). The results of this categorization are shown later in Section 3.3. The Analyst then conducted a detailed data extraction process. This entailed reading or skimming the document for mention of Earth observations, and recording all mentioned Earth observation parameter information in a spreadsheet organized by parameter and document. Each row in the spreadsheet represented a document, and each column represented a parameter (e.g., wind speed), facilitating a quick review of the total information gleaned, either by document or parameter. The Analyst recorded all relevant information provided in the document, including any mention of desired parameter characteristics

In cases where the information in the document referred to the *adequacy* of the characteristics of a current observation rather than the *ideally required* parameter characteristics, the parameter characteristics of the current observation were recorded for reference purposes. For example, if a document indicated that current spatial resolution of wind speed data is inadequate, the spatial resolution of the current observation referenced in the document, if specified, was recorded (such as on a 10km x 10km grid). While this information on adequacy of current observations does not provide an absolute target of ideally required parameter characteristics, this information was used to fill gaps where information was lacking on ideally required parameter characteristics. A distinction between the information derived from these two approaches is clearly made in the results section of this document.

The next step was to construct a table of priority observations for each renewable energy sub-area, as described in Section 3.2. To do this, the Analyst noted whether there were one or more documents for each sub-area that addressed ideally required user needs, as opposed to the adequacy of current observations. For solar and wind energy, such documents addressing ideally required user needs were available, and these “primary” documents were used as an initial basis to construct a priorities table for those sub-areas. The Analyst then compared the needs in these primary documents to parameters identified in other relevant documents, and added parameters to the table in cases that did not contradict the primary sources. Where there was a parameter that was indicated as important by three or more documents, but not the primary document, the Analyst included it in the table, but flagged such parameter as not derived from a primary user needs document.

For the renewable energy sub-areas other than solar and wind energy, the Analyst and Advisory Group were not able to identify any clear-cut surveys or reports focused on end user needs. Thus, the Analyst pieced together the priority needs from the remaining relevant documents.

2.3.3. Prioritization Methods

The Analyst developed a linear method of prioritization of the Earth observation parameters identified through the document meta-analysis described in Section 2.3.2 above. The Advisory Group reviewed the method of prioritization. Only two Advisory Group members made minor comments on the method.[3] The three consecutive steps of this prioritization are as follows:

- Cross-Cutting Parameters: The first step in identifying Earth observation priorities was for the Analyst to assess which observation parameters are required, with similar scales and characteristics, across several of the six sub-areas of renewable energy. The Analyst deemed that parameters that are required for multiple types of renewable energy would have an “economy of scale” that provides a multi-faceted return on investment. To ensure that these parameters are required with similar scales and characteristics, the Analyst checked the original literature and noted where required characteristics between renewable energy sub-areas varied significantly. However, in many cases, although the ideally required scales varied, meeting the finer scale requirement (e.g., hourly data) for one renewable energy sub-area would also allow averaging to meet a coarser scale requirement (e.g., monthly averages) for a different renewable energy sub-area.

- Key Parameters for Priority Renewable Energy Types: The second step was for the Analyst to identify the renewable energy types that are projected by experts to gain prominence over the next 20 plus years. For this, the Analyst relied on the International Energy Agency’s (IEA) World Energy Outlook 2008 (IEA, 2008b). The World Energy Outlook draws on a worldwide body of experts to identify required actions in the energy

[3] One Advisory Group member suggested that an output of multiple prioritization lists would be preferable to a single list. However, to meet the purpose of Task US-09-01a, a single list (Table 11) was still developed, but the individual lists that fed into the single list were left intact for those wishing to focus on those lists instead (Tables 9 and 10). A second Advisory Group member suggested retaining CSP in Table 10.

realm for a sustainable future. The Reference Scenario presented in the World Energy Outlook projects the energy mix out to 2030. The Analyst deemed that the top four renewable energy types by Terawatt-hours generated in the 2030 Reference Scenario should be considered "priority" types in this US-09-01a analysis. These were hydropower, onshore/land-based wind, bioenergy, and offshore wind.

- Advisory Group Refinement: The third step was oversight and review from the Task US-09-01a Energy SBA Advisory Group of the observation priorities identified by one or both of the first prioritization steps. This also served as a final check, should one of the above two methods fail to identify or properly categorize an observation. When combined with additional analysis by the Analyst, this allowed for ordering the parameters identified by the two methods above into a single tiered set of parameters.

3. Energy SBA

3.1. Description

The GEOSS 10-Year Implementation Plan notes that the Energy SBA is focused on improving management of energy resources. Section 4.1.3 of the 10-Year Implementation Plan describes the Energy SBA as the following:

> "GEOSS outcomes in the energy area will support: environmentally responsible and equitable energy management; better matching of energy supply and demand; reduction of risks to energy infrastructure; more accurate inventories of greenhouse gases and pollutants; and a better understanding of renewable energy potential."

The scope of the GEO Energy SBA includes both energy derived from non-renewable energy sources (e.g., coal, oil, and gas) and from renewable energy sources (e.g., as listed in the Renewable Energy Sub-areas Section 3.2). For either of these broad energy types, the Energy SBA includes aspects from exploration and production to monitoring, operation, and forecasting activities required for energy facilities. The Energy SBA also includes energy applications such as cooking, generating heat, and transportation fuels, rather than electricity generation applications. Further, transportation and consumption of energy falls within the Energy SBA, as does assessment of environmental impacts and reduction of weather-related and other risks to energy infrastructure. Finally, improved technologies for stabilizing or reducing greenhouse gas emissions, and the need to report energy emissions levels to bodies such as the United Nations Climate Change Convention fall within the Energy SBA. Note that Climate is identified as a separate SBA by GEO, although closely linked with the Energy SBA.

3.2. Renewable Energy Sub-areas

In order to bound the Task US-09-01a analysis to a manageable scope, the Analyst made a preliminary decision in consultation with selected members of the UIC (Personal communication with UIC co-leads of Task US-09-01a, Ellsworth LeDrew, University of Waterloo, Canada and

Lawrence Friedl, NASA Applied Sciences Program, Washington, DC, March 2008) to focus on renewable energy. Upon assembly of an Advisory Group in a teleconference in December 2008, the Advisory Group concurred that renewable energy, and all its sub-areas, is an appropriately sized subset of related topics that would lend itself well to this analysis task. As noted below, although all renewable energy areas were candidates for analysis, the Analyst and Advisory Group determined that six sub-areas of renewable energy should be thoroughly analyzed.

One of the documents identified was helpful in determining which subsets of renewable energy to include in the analysis. As such, the Analyst relied on the International Energy Agency's (IEA) World Energy Outlook 2008 to identify renewable energy sub-areas. The IEA document represents a consensus document as it draws on a worldwide body of experts and presents a projection of the world energy mix out to 2030, shown in Figure 1. The Analyst used the IEA document both for scope selection and for Earth observation prioritization, as noted previously.

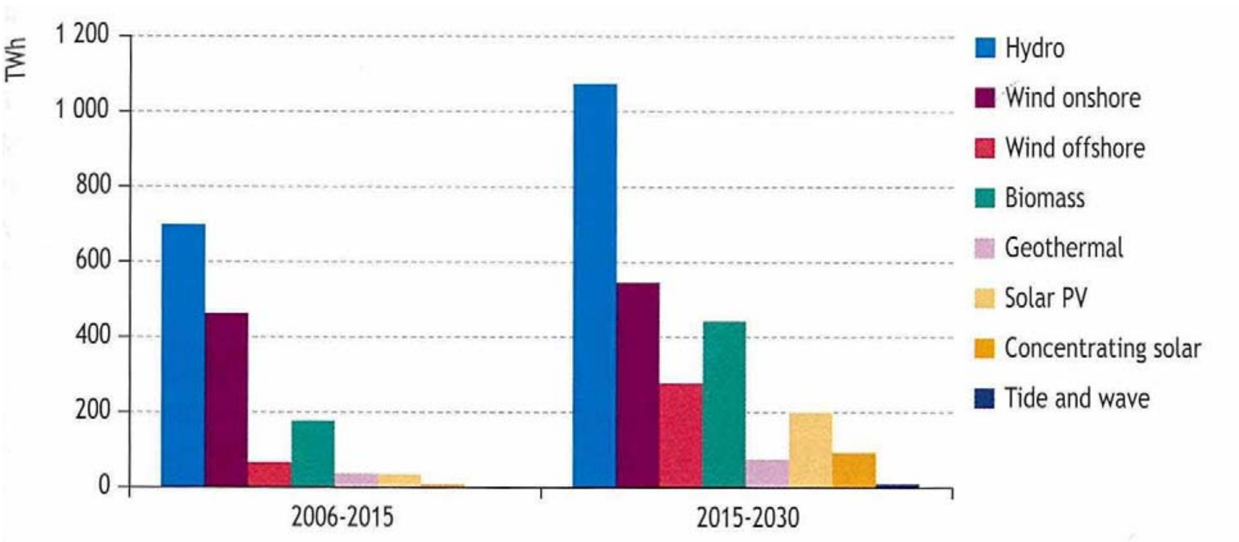

Figure 1. Increase in World Electricity Generation from Renewable Energy in the World Energy Outlook 2008 Reference Scenario.

Source: IEA 2008b, Figure 7.3

The Analyst, in consultation with the Advisory Group, decided for the purposes of this analysis that all renewable energy sub-areas that appeared in the IEA projection would be prominent enough now and in the future that they could be included in the analysis. The Advisory Group confirmed this assumption. However, given limited resources, tide/wave energy was not included (as it is projected to be the smallest in both timeframes) and Solar PV and CSP were considered together. The Advisory Group also noted that including all of the remaining sub-areas is key because different sub-areas are important to different regions, and certain sub-areas are especially relevant in developing countries. In particular, several Advisory Group members

encouraged the inclusion of bioenergy and hydropower (particularly micro- and small-scale) as important sub-areas for developing countries.

The Analyst chose to focus on renewable-based electricity generation because it is the primary application for most renewable energy sub-areas. Renewable-based electricity generation is projected to increase more than two-fold over the next 20-plus years. The share of total electricity output from renewable sources is anticipated to rise from 18% in 2006 to 23% in 2030, becoming the second largest source of electricity (behind coal) by 2015 (IEA, 2008b). This choice to focus on electricity generation allowed for parallel analyses among renewable energy sub-areas, and also maintained a manageable scope. This selection of renewable-based electricity generation excludes applications such as solar heating and use of bioenergy or geothermal energy for heating or cooking. The Advisory Group did not raise any objections to such scope narrowing (although they did comment on other scope exclusions such as the initial exclusion of geothermal energy, which ultimately was included in the analysis).

Thus, the six major renewable energy sub-areas included in this analysis are briefly described below. For more information on each of these sub-areas, refer to the GEOSS Energy Community of Practice website (http://www.geoss-ecp.org/) or the IEA "Renewable Energy RD&D Priorities 2006" (IEA, 2006):

- Solar Energy: The generation of electricity from the sun's energy, typically accomplished by photovoltaics (PV) or concentrating solar power (CSP). PV cells convert sunlight directly into electricity and are made of semiconductors. CSP technologies use reflective materials to concentrate the sun's heat energy to drive an electric generator (IEA, 2006). Note that while most documents identified focused on generation of electricity from solar energy, one primary source (Huld et al., 2007) for the analysis actually addressed solar energy broadly, including solar heating and cooling, and thus goes beyond the overall electricity generation focus of this report.

- Wind Energy (onshore or land-based): The generation of electricity from turbine facilities located on land. An accurate understanding of magnitude and consistency of wind resources is critical in determining where to locate wind generation facilities.

- Wind Energy (offshore): The generation of electricity from wind turbine facilities located away from land on coastal or oceanic sites.

- Hydropower: The generation or storage of electricity from water flow, in some cases through lakes and reservoirs. This report includes micro-hydropower (typically 300 kW or less), small hydropower (typically 10 MW or less), and large hydropower (typically greater than 10 to 50 MW).[4]

[4] Both micro- and small hydropower tend to be run-of-the-river facilities that do not interfere significantly with river flows, and are thus considered environmentally benign and more clearly within the category of renewable energy than reservoir hydropower applications. However, the documents analyzed did not provide a clear distinction between Earth observations required according to application size, and thus all application sizes were included for completeness.

- Bioenergy: The generation of electricity from any plant or animal matter, typically through combustion processes. Bioenergy has little or no net emissions and thus is viewed as renewable resource.

- Geothermal Energy: The generation of electricity based upon the use of heat in the earth. Large amounts of heat at or below the surface can be used to generate pressurized steam to power electric turbines and/or heat nearby structures. This analysis focuses on electricity generation.

3.3. Documents

In total, 61 documents were identified by the Analyst and the Advisory Group as being potentially relevant to earth observation priorities related to the renewable energy sectors chosen for this report. Of these initial documents, the distribution among the sub-areas was as follows:

22 (36.1%) addressed solar
19 (31.1%) addressed offshore wind
20 (32.8%) addressed land-based wind
14 (23.0%) addressed hydropower
11 (18.0%) addressed bioenergy
17 (27.9%) addressed geothermal energy.

Although all of these documents were reviewed, ultimately only 47 of the 61 (77%) contained specific details regarding earth observations, either current or desired, and were included in the analysis. A list of the 47 references included in the analysis is included in the Appendix, although not every report is cited individually throughout the text of this document.

As described in Section 2.3.1, the Analyst sought out documents from a variety of sources with the intent of being representative of both global views and regional views. Of the 47 documents included, the distribution by region and sub-area is shown in Table 2.

Table 2. Document Sources for Energy SBA.

Geographic Region	Number of Documents		Sub-area	Number of Documents
International	19		Wind (land-based)	14
Africa	4		Wind (offshore)	15
Asia/Middle East	7		Solar	14
East Asia	8		Hydro	11
Europe	15		Bioenergy	9
North America	8		Geothermal	14
Oceania/Australia	3			
Polar Regions	0			
South/Central America	3			

The number of areas represented and the number of sub-area topics do not equal the total number of documents because some documents represented multiple regions and/or sub-areas. During the process of gathering documents, the Analyst periodically tracked the number of sources from each region and sub-area, and sought out additional documents from those regions and sub-areas which were under-represented through the Advisory Group and literature searches.

4. Earth Observations for Energy SBA

4.1. Solar Energy

Of the 14 documents identified for solar energy, the most directly relevant of these documents was a survey conducted by the GEO Energy COP of solar energy data end users (Huld et al., 2007). A second document of direct relevance described the European Space Agency (ESA)-sponsored ENVISOLAR program (Environmental Information Services for Solar Energy Industries) and how it meets user needs (Bofinger et al., 2007). The COP survey and the ESA document were the only documents identified by either the Analyst or the Advisory Group that directly addressed user needs without being limited to currently available or planned technologies and observations, and were thus considered “primary” sources as described in Section 2.3.2.[5]

The remaining 12 documents fell into the category of addressing use of currently available data with indication of its adequacy in meeting user needs. Such documents came from organizations such as the IEA, United Nations Environment Programme (UNEP), NASA, and U.S. Department of Energy National Renewable Energy Laboratory (NREL). These documents were either official reports of the agency or online documentation of data needs and uses related to solar energy. The remaining documents were five peer-reviewed journal articles that described current applications of Earth observations with respect to solar energy and any noted shortcomings. The journal articles typically had multiple authors and often included representatives from the organizations noted above.

The Analyst considered all of these types of documents valid for inclusion in the analysis, as they either represented broad consensus of an organization or included one or more authors affiliated with an internationally recognized organization. Further, there were no parameters that were called for by just one document, and thus, there were no “outlier” documents or parameters to consider excluding. Thus, the Analyst conducted the detailed extraction process described in Section 2.3.2 for each of the 14 most relevant documents.

[5] Note that this document covered all uses of solar energy, including electricity and solar energy for heating and cooling. Thus, Huld *et al.*, 2007 can be considered to represent the broader category of solar energy beyond electricity generation, although the remaining solar energy documents mentioned in this report focused on electricity generation alone.

Because it was used as one of the primary document for analysis, the Analyst examined the geographic breakdown of the GEO Energy COP user survey respondents. Out of 111 respondents, 85% were from Europe, and the rest were roughly equally distributed among Asia, Africa, and North America, with South/Central America being least represented, and Australia being notably absent from the survey respondents. Thus, the document offers a limited degree of global representation. The Analyst augmented this primary document with the ENVISOLAR document that included broader geographic representation, including projects being implemented in Africa and Asia, and other documents as classified in Section 3.3.

The Earth observation requirements for generation of electricity from solar energy outlined in the documents are presented in Table 3. The Analyst constructed this table following the methodology described in Section 2.3.2. For the GEO Energy COP survey results, the Analyst chose to consider parameters or parameter characteristics that were ranked highly by approximately half or more of survey respondents as high-ranking, worthy of inclusion in Table 3. The Analyst then supplemented these parameters with those identified in the ENVISOLAR document (Bofinger et al., 2007), and added to this list with parameters from other relevant documents. A summary of all information from the documents on the required parameter characteristics follows Table 3 – this discussion includes all information from the source documents reviewed. Details of some required parameter characteristics are not included because they are not present in the source documents.

Table 3. Earth Observation Parameters for Solar Electricity Generation Applications.

Parameter Type	Priority Parameters
Characterization of Solar Resource	Direct normal irradiation (DNI)* Diffuse irradiation* Global horizontal irradiation (GHI)* Inclined plane radiation* Cloud cover (cloud index) Circumsolar ratio*
Meteorological Parameters	Wind speed Wind direction Ambient air temperature*
Atmospheric Composition	Aerosol optical depth (AOD)* Water vapor content Atmospheric ozone content

* Indicates parameters that are derived rather than measured directly. Note that some derived parameters listed here may rely upon the measured parameters also listed in this table.

DNI and GHI are derived parameters calculated with a radiative transfer equation incorporating the measurements of the cloud index and atmospheric composition, according to several documents. Thus, although parameters such as cloud index, AOD, atmospheric ozone content, and water vapor content were not identified explicitly as of interest to end users in the GEO Energy COP survey document, the Analyst included these parameters in Table 3 as priority observations (on which other priority observations rely). The need for DNI, GHI, or both depends upon the specific solar technology under consideration by the user (Cogliana et al.,

2008). Further, the required parameter characteristics of DNI and GHI, and other parameters listed in Table 3, depend upon the intended use of the data, such as the stage of the application (site selection vs. planning vs. operation). The documents indicated that, in general, earlier stages such as resource assessment of a country require relatively coarse spatial and temporal resolution data, while individual project planning and operation require increasing degrees of resolution. Note, however, that the GEO Energy COP survey was designed such that the parameter characteristics desired were not linked to the parameter(s) of particular interest to an individual respondent, making it difficult for the Analyst to connect parameters with precise desired characteristics. Thus, the following discussion applies generally to the solar energy parameters as listed in Table 2 above.

The GEO Energy COP survey document indicated that there is more end user interest in long-term averages (annual or monthly) than in very short-term averages (less than 1 hour), with the most popular being monthly averages. However, another document indicated that GHI is needed in at least hourly temporal resolution, particularly for solar technology simulations during project planning and for reliability checks during plant operation (Bofinger et al., 2007). The Analyst noted that this apparent contradiction likely stems from the fact that the documents addressed different users -- many of the GEO Energy COP survey respondents were system planners, while the second set of documents focused on utilities operating a renewable energy facility. The documents indicated that facility operators have a need for more real-time, short-term average data (e.g., up to 15-minute intervals). The GEO Energy COP survey respondents also indicated that timeliness of data is not particularly important, with data from last month, year, or older archives being the most needed. Other documents did not address timeliness of data.

In terms of spatial resolution, the GEO Energy COP survey document indicated that a spatial resolution of 300 km^2 did not satisfy most respondents – typically 5 km^2 to 10 km^2 was requested, although about half the respondents indicated a high level of interest in the 1 km^2 detailed maps. One document also noted that for many solar applications like PV power grid interaction studies or large solar energy systems, irradiance measurements integrated over a pixel-size ground area (e.g., 5 km^2) are needed by end users more than single-point measurements (e.g., such as from a ground-based station) (Bofinger et al., 2007). In the absence of additional information on ideally required spatial resolution, the Analyst referred to other documents that address spatial resolution relative to currently available data. Such other documents generally confirmed the survey results, although quantified spatial resolution from a single-point perspective rather than a gridded resolution. Such other documents noted, for example, that an unspecified increase in concentration of DNI measurements in India, Italy, and Spain (above an unspecified current level) is needed, and that underdeveloped regions such as parts of Africa lack single-point data entirely. Only one document provided any quantification of the need for higher spatial resolution, noting that, in Germany, the density of ground stations is one per 8500 km^2, which the document stated is inadequate (Bofinger et al., 2007).

The documents presented a wide range of information on accuracy, although all documents focused on the accuracy of current information rather than the absolute quantitative terms of accuracy required by end users. The ENVISOLAR document (Bofinger et al., 2007) noted that the accuracy of existing solar resource information was considered adequate by end users. The

ENVISOLAR document stated that GHI accuracy ranges from 5 to 20 % relative root mean square error (rRMSE), and DNI accuracy ranges from 15 to 35% rRMSE, with both showing higher accuracy for monthly compared to hourly values. On the contrary, the GEO Energy COP survey document indicated that many more respondents are "strongly dissatisfied" than "satisfied" with the accuracy of current solar data. No specification was provided in the GEO Energy COP survey of the target or required improvement in accuracy.

Several documents indicated that forecasted parameters, such as GHI and DNI, are required for efficient operation of a facility and planning for grid integration, anywhere from hours to months ahead (Huld et al., 2007 and Bofinger et al., 2007). The documents indicated that forecasted parameters are typically derived from forecast models that rely upon inputs of current and historical parameters, such as meteorological observations. The need for forecasted parameters gives added importance to the need for observation of meteorological parameters, along with development and refinement of appropriate models. However, no specifics were provided on the parameter characteristics required for such models to meet end user needs.

4.2. Wind Energy (Land-based and Offshore)

Of the 19 documents identified for wind energy (14 discussed land-based wind energy and 15 discussed offshore wind energy, with significant overlap) the most directly relevant was a survey conducted by the GEO Energy COP of wind energy data end users (Ranchin et al., 2007). A second document of direct relevance was a European Wind Energy Association prioritization of strategic wind energy research needs (EWEA, 2005). These two documents were the only documents identified by either the Analyst or the Advisory Group that directly addressed user need without being limited to currently available or planned technologies and observations, and were thus considered "primary" sources as described in Section 2.3.2.

The remaining 17 documents fell into the category of addressing use of currently available data with indication of its adequacy in meeting user needs. Similar to the solar energy documents discussed above, such documents came from organizations such as the IEA, UNEP, NASA, and NREL. These documents were either official reports of the agency or online documentation of data needs and uses related to wind energy. The remaining documents were six peer-reviewed journal articles that described current applications of Earth observations with respect to wind energy and any noted shortcomings. The journal articles typically had multiple authors and often included representatives from the organizations noted above. Consistent with the analysis for solar energy, the Analyst considered all of these types of documents valid for inclusion in the analysis. Thus, the Analyst conducted the detailed extraction process described in Section 2.3.2 for each of the 17 most relevant documents.

Because it was used as one of the primary documents for analysis, the Analyst examined the geographic breakdown of the GEO Energy COP user survey respondents. The survey respondents were heavily biased toward Europeans (75%), with 13% from North America, 8% from Oceana, and 4% from Africa. The Analyst augmented this primary document with the EWEA document, also biased toward Europe, and brought in other documents where available to provide geographic diversity, as classified in Section 3.3.

The Earth observation requirements for wind energy outlined in the documents are presented in Table 4. The Analyst constructed this table following the methodology described in Section 2.3.2. For the GEO Energy COP survey results, the Analyst chose to consider parameters or parameter characteristics that were ranked highly by approximately half or more of survey respondents as high-ranking, worthy of inclusion in Table 4. The Analyst then supplemented these parameters with those identified in the EWEA document (EWEA, 2005), and added to this list with parameters from other relevant documents. A summary of all information from the documents on the required parameter characteristics follows Table 4 – this discussion includes all information from the source documents reviewed. Details of some required parameter characteristics are not included because they are not present in the source documents.

Table 4. Earth Observation Parameters for Wind Energy.

Parameter Type	Priority Parameters
Meteorological Parameters	Wind speed Wind direction Vertical wind profile Turbulence Wind shear Dew point Ambient air temperature Atmospheric pressure
Land Parameters	Topography/elevation Land cover Tree cover density Surface roughness
Offshore Environment Information	Wave height Current speed Tides Bathymetry Sea surface temperature

Earth observation parameters are required for assessing wind resources and assessing the environment (onshore or offshore) where a wind energy facility may be located. In addition, facility operation and maintenance, cost assessment, grid integration, and energy trading are among the other user applications of Earth observation data (Ranchin et al., 2007). The required parameter characteristics depend upon the intended use of the data. The Analyst tried to capture the broad range of potential uses in the following discussion. However, note that the respondents to the GEO Energy COP survey were fairly heavily skewed toward those interested in feasibility studies, site selection, and investment decisions, as opposed to system design and operation functions.

Most of the documents that addressed wind energy end user needs focused on the required characteristics of the meteorological parameters listed in Table 4, and specifically on wind speed, direction, and vertical wind profile. Thus, the discussion below focuses primarily on these three parameters, including specification of the exact parameter referenced when available. The

discussion concludes with the limited information that the Analyst found in the documents on required characteristics of the other meteorological parameters, land parameters, and offshore environment information included in Table 4.

The GEO Energy COP survey document indicates a broad range of end user needs in terms of horizontal spatial resolution of data. The highest ranking spatial resolutions requested by end users ranged from 100 m^2 to 10 km^2, all of which were ranked roughly equally. In the absence of additional information on ideally required spatial resolution, the Analyst referred to other documents that address spatial resolution relative to currently available data. Such other documents generally confirmed the survey results. Many documents made a distinction between single point measurements (i.e., ground-based) and gridded products (i.e., airborne or satellite-based), noting that both types are needed as they have different uses and help validate each other. Thus, the Analyst chose to report separately on the spatial resolution of these two distinct types of measurements rather than group them together and risk losing the importance of either range of spatial resolutions:

- For gridded data, several documents noted that the 1 km^2 scale (e.g., as currently available from airborne synthetic aperture radar, or SAR) is adequate for end users mapping the fine spatial details in wind speed variations over the ocean, while coarser scale data (e.g., approximately 25 km^2 scale currently available from scatterometers such as QuikSCAT) is needed for large-scale wind resource assessment. For onshore wind resources, no documents directly addressed the adequacy for end users of current spatial resolution. The Analyst did infer, however, that the 400 m^2 to 100 km^2 scale state-of-the-art products from programs such as SWERA are meeting current user needs (potentially distinct from ideally required user needs).

- For single point measurement data, the documents (e.g., UNEP, Unknown Date) agreed that the current (unspecified) density of measurements is inadequate, without quantifying a higher spatial resolution required by end users.

One primary document by the EWEA addressed horizontal spatial coverage, noting that there is a need for mapping wind speed and direction for many offshore areas. The EWEA document recommends mapping of the Baltic, North, and Black Seas (EWEA, 2005). The need for more mapping of offshore areas was confirmed by many other documents highlighting the inadequacies in coverage of wind speed and direction measurements. Near-shore areas (5 to 50 km offshore, where wind facilities are likely to be located) have only partial coverage from SARs, and scatterometers do not cover such areas.

The GEO Energy COP survey document and several other documents indicated the importance of vertical wind profiles to end users, without providing specifics on height ranges needed. In addition to profiles, the documents agreed that wind speed, direction, and turbulence measurements are needed at wind turbine hub height, which has generally been increasing over the years. Hub height varies from 10 to 30 m for land-based rural power, to 30 to 80 m for land-based utility scale power, to 100 to 200 m for offshore wind facilities (Barthelmie et al., 2005 and Ranchin et al., 2007).

In terms of temporal resolution, the GEO Energy COP survey document found a very wide range of user needs. While hourly average data were identified as the most important, following very close behind was a wide range of temporal resolutions, from 5 minute to annual averages (Ranchin et al., 2007). Several other documents indicated that hourly or finer data (down to 10 minutes) are needed for near-ground level historical data used to plan a wind generation facility, and hourly data are needed for vertical wind profiles that support wind modeling (e.g., U.S. NASA, 2008). For annual average data, such as that which might be derived from a long-term record of scatterometer data, better (unspecified) diurnal variation is needed (i.e., to capture different parts of a day with varying wind speeds).

Several documents addressed the required timeliness of wind resource data, although with somewhat conflicting information. In the GEO Energy COP survey document, approximately ¾ of respondents value older data (one month to several years old), while only 1/3 of respondents value data from the most recent hours or days. However, the EWEA document indicated that "immediately available" data are particularly relevant for operators of large wind farms and for wind forecasting. Thus, this apparent contradiction in required timeliness can be explained by the different uses of the data (the GEO Energy COP survey respondents tended to be facility planners rather than operators). Several documents also stated that near-real time availability (unspecified) of data, such as that from SAR and scatterometers, is useful to end users.

A majority of the documents noted that an improvement in accuracy over that of current wind resource information is needed. The EWEA document summarized this consensus best, noting that an error of 10% between measured and actual wind speed is "too much" for financiers, insurers, and project developers. This error value of 10% was actually cited in a contrasting manner by another document (U.S. NREL, Unknown Date) which noted that an annual average wind speed within 10% is adequate to stimulate the development of wind energy in a study region. The Analyst notes that this apparent contradiction could be due to different averaging times (short-term in the EWEA document vs. annual averages in the NREL document). One document clarifies that errors are higher for short-term averages and lower for longer-term averages (U.S. NASA, 2008). Nevertheless, the need for improved accuracy was prioritized as an urgent "show stopper" by EWEA, which named some specific technologies (e.g., sonic detection and ranging, or SoDAR, and light detection and ranging, or LiDAR, and satellite-based technologies) that require accuracy improvements. For reference purposes, the documents noted that the current accuracy of satellite-based wind resource data, for example, is within "a few m/s" for wind speed and approximately 20 degrees for wind direction (Mathieu, 2005).

The GEO Energy COP survey document indicated that topography data was ranked only slightly lower than wind speed and direction as being important to end users. However, the survey did not include any specific required parameter characteristics for topography, but rather addressed spatial resolution generally for all parameters. Other documents provided some insight on the required spatial resolution of topography, by referencing the adequacy of the spatial resolution of current topography data. The documents indicated that current topography data at 1 km^2 resolution is adequate for regional but not local wind resource assessments, and that finer gridded data is needed to improve the accuracy of wind model outputs (Elliott et al., 2001 and

U.S. NREL, Unknown Date). The required spatial resolution also depends on the relief in the area, and contour maps of 5 to 10 m elevation intervals are being used for wind facility planning studies.

For the other meteorological parameters, land parameters, and offshore environment parameters listed in Table 3, the Analyst found very limited information in the documents on required parameter characteristics, as follows:

- The GEO Energy COP survey noted the need for offshore environment information, including wave height, tides, currents, bathymetry, and sea surface temperature. Wave heights were indicated as being needed in a wide range of temporal resolutions, primarily in hourly to monthly averages (but with moderate interest in data down to 15-minute averages). The survey did not provide any additional information on required parameter characteristics of the offshore environment. Two other documents addressed the need for offshore environment information for wind energy applications. The first (Mathieu, 2005) confirmed the need for sea surface temperature without specifying parameter characteristics. The second (Boud, 2003) noted that the prediction of wave heights from a few hours to a few days out is needed for operation and maintenance of offshore wind facilities, but did not specify the underlying Earth parameters required for such prediction.

- Several documents discussed the need for meteorological parameters such as dew point, ambient air temperature, and atmospheric pressure for inputs to wind resource models. These documents did not specify required parameter characteristics, but noted that such meteorological parameters are increasingly needed in higher temporal and spatial resolution to keep pace with improving models. For reference purposes, one document indicated that the current temporal resolution of wind resource models is hourly, and that increased (unspecified) spatial resolution is needed to correspond with each node of the high voltage grid (Lange et al., 2006).

- Several documents addressed land parameters needed for wind resource models and for micro-siting of facilities, without specifying required parameter characteristics. The land parameters included classified land cover and tree cover density for use in calculating surface roughness. Also, one document written by an Advisory Group member stated a need for improved methods of interpreting surface reflectance data to differentiate snow cover from clouds (U.S. NASA, 2008).

4.3. Hydropower

Unlike the areas of solar and wind energy, neither the Analyst nor the Advisory Group identified any documents that directly address ideally required user needs for hydropower. Thus, the following analysis relies upon the 14 identified documents that indirectly address user needs for hydropower-related Earth observations, by focusing on the adequacy of current observations.

The 11 relevant documents included two IEA documents, seven peer-reviewed journal articles, one government report, and the website of the U.S. Department of Agriculture, Foreign Agricultural Service. While not an ideal mix of document types, the documents represented reasonably broad geographic coverage, including Asia, Africa, Europe, and North America, and both developed and developing countries. The Analyst conducted the detailed extraction process described in Section 2.3.2 for each of the 11 most relevant documents.

The Earth observation requirements for hydropower outlined in the documents are presented in Table 5. The Analyst constructed this table following the methodology described in Section 2.3.2. A summary of all information from the documents on the required parameter characteristics follows Table 5 – this discussion includes all information from the source documents reviewed. Details of some required parameter characteristics are not included because they are not present in the source documents.

Table 5. Earth Observation Parameters for Hydropower.

Parameter Type	Priority Parameters
Water Parameters	Stream/river flow Lake/reservoir height Snow water equivalent* Water runoff Groundwater storage
Meteorological Parameters	Precipitation Evaporation* Tropopause temperature Wind speed Near-surface water and sea-surface temperature (for large lakes) Humidity Pressure Cloud cover
Land Parameters	Topography/elevation Land cover* Snow cover* Synthetic aperture radar images

* Indicates parameters that are derived rather than measured directly. Note that some derived parameters listed here may rely upon the measured parameters also listed in this table.

Similar to other renewable energy types, different stages of hydropower assessment, development, and operation require different sets of Earth observations. In addition, the different scales of hydropower require different information (e.g., stream flow, reservoir height) at different scales (e.g., ranging from meters to kilometers). Earth observations are needed for hydropower projects to identify and develop potential sites, conduct site management and operations, and conduct historical analysis on the performance of hydropower projects.

More so than for other renewable energy technologies, hydropower at a large scale also involves assessment and mitigation of environmental impacts, requiring additional Earth observation parameters related to ecosystems and biodiversity. This report does not focus on such

environmental assessment parameters, deferring instead to the Ecosystem and Biodiversity SBA GEO Task US-09-01a reports for that analysis.

Some of the parameters included in Table 5 are derived parameters that are based on other parameters also listed in Table 5. For example, snow cover and snow water equivalent are based on underlying parameters of topography, synthetic aperture radar images, cloud cover, and land cover classification (also a derived parameter) (Larsen et al., 2005). Evaporation is based on wind speed, near-surface and sea-surface temperature, humidity, and pressure. Water run-off requires hydrology and meteorology data as well as snow cover and NWP models. Thus, the required characteristics of the hydropower parameters are inter-related. The limited information provided in the documents on such parameter characteristics is summarized below.

Because the scale of hydropower projects varies dramatically (from several meter-wide streams to reservoirs that are tens of kilometers across), the Analyst notes that the required spatial resolution of the relevant parameters varies as well. However, neither the Analyst nor the Advisory Group identified any documents that addressed user needs or quantified the adequacy of current spatial resolution. The following information is included, for reference, to convey the overall scale of current parameters, with the recognition that this does not represent ideally required user needs:

- The documents addressed snow cover and snow water equivalent as parameters required by hydropower companies. To meet this user need, the EO-Hydro Service within the ESA Earth Observation Market Development (EOMD) Program provides snow cover at 250 m^2 spatial resolution, and snow water equivalent at 375 m^2 resolution (Larsen et al., 2005). A separate snow water equivalent product, which is currently available at a 7 km^2 scale, is considered too coarse for operational deployment.

- The documents addressed precipitation as an important parameter for hydropower. These documents noted that precipitation data are currently available on a spatial resolution of 0.25 by 0.25 degrees for tropical regions (from the Tropical Rainfall Measuring Mission [TRMM], in a data product that integrates ground-based rain gauge data). Another document addressed the inadequate spatial coverage of ground-based rain gauge data for large-scale hydropower projects, only indicating that such gauges are “sparse.”

- The documents noted that lake or reservoir heights are currently available as an average lake-height along a satellite track, from about every 350 m to 580 m (as provided by satellite altimeters such as the NASA/Centre National d'Etudes Spatiales (CNES) Topex/Poseidon and Jason-1 and Jason-2 satellites).

- Groundwater storage is currently available on the spatial scale of a few hundred kilometers or greater (e.g., from the Gravity Recovery and Climate Experiment, GRACE).

In terms of spatial coverage, the documents did not address ideally required information, but did give some indication of currently available coverage. For example, lake or reservoir heights

provided through the U.S. Department of Agriculture (USDA) Global Reservoir and Lake Monitor project cover approximately 100 lakes worldwide, and other services (e.g., from the French space agency CNES) include a broader set of lakes (Swenson and Wahr, 2009 and U.S. Department of Agriculture, 2009). The precipitation data provided by TRMM covers the tropics between 35 degrees north and south. One document did note that classification of satellite imagery is needed for identification of potential small and micro-hydropower resources in complex terrain (e.g., in mountainous areas of India) (Dudhani et al., 2006).

One document addressed the current temporal resolution of lake and reservoir height data, noting that, depending on the satellite, the data are available every 10 to 35 days, approximately 7 to 10 days after satellite overpass. No indication of adequacy was provided. Timeliness was also addressed in terms of the adequacy of some current methods of data collection (Dudhani et al., 2006). Topographical surveys that are 8 to 10 years old are considered too old for small-hydropower and micro-hydropower project implementation, implying a need for topographical data that are updated in a more timely fashion. Finally, the timeliness of the EO-Hydro Service water run-off product was characterized as near-real time, and designed as such to meet hydropower company needs.

Several documents addressed the adequacy of the accuracy of currently available information, although primarily in a qualitative manner:

- Lake or reservoir heights (provided through the USDA Global Reservoir and Lake Monitor project) have accuracy within 10 cm RMS, or 3 to 4 cm RMS for large lakes. The document indicated that this accuracy is considered "excellent" and is adequate for estimating lake discharge (Swenson and Wahr, 2009 and U.S. Department of Agriculture, 2009).

- Groundwater storage information from GRACE has accuracy, for example, over the Caspian Sea of approximately 5 cm RMS, indicated as "quite consistent," on seasonal and inter-annual timescales (Swenson and Wahr, 2009).

- Precipitation data from TRMM, when compared to rain gauges in Ethiopia near Lake Victoria, showed errors of about 25% RMS, and biases of about 10%. A similar comparison study with rain gauges in West Africa found RMS errors of about 1 mm/day for monthly merged rainfall estimates (Swenson and Wahr, 2009). No indication of the adequacy of this accuracy was stated.

- The accuracy of the snow cover and snow water equivalent parameters provided by the EOMD program is not currently publicly available because it is based on comparison with ground-based observations that are the property of hydropower companies. However, the accuracy is reported to be satisfactory to the end users (Tampellini et al., 2007). A separate document on snow water equivalent in Norway noted that the product had to be averaged to 7 km by 7 km to obtain "sufficient accuracy," without providing further quantification.

4.4. Bioenergy

Similar to hydropower, the Analyst and Advisory Group did not identify any documents that directly addressed the ideal Earth observation priorities for bioenergy through user surveys or similar documents. Therefore, this analysis is based upon the nine (9) identified documents that indirectly address these user needs for bioenergy-related Earth observations, focusing on the level of adequacy of currently reported observations.

In remaining consistent with the methodology presented previously, this document focuses on the share of biomass used for electricity generation. Electricity production is currently a small portion of total bioenergy use but is expected to grow over time. In 2000, approximately 40 GW of biomass-based electricity production capacity was installed worldwide, producing 0.6 EJ electricity per year (IEA, 2007). The global share of biomass in global electricity generation is projected to be 2.6% by 2030 (IEA, 2008b).

The key determinant of the Earth observation parameters required for bioenergy is the source of the biomass. The three major categories of biomass are:

- Residues (e.g., from forestry and agriculture activities, or industrial facilities)
- Organic waste streams (e.g., methane from landfills)
- Purpose-grown energy crops (e.g., grass production on pasture land, wood plantations and sugar cane on arable land).

Purpose-grown energy crops, and to a lesser extent residues, stand to benefit the most from Earth observations. Organic waste streams are typically from facilities that are managed and monitored independently. Specific crops that may be used for electricity generation vary greatly by region, and are strongly influenced by market conditions and agricultural policies. A crop-specific analysis of Earth observation parameters for bioenergy would be speculative at best.

This bioenergy analysis focuses generically on the Earth observation parameters useful for agriculture, given that energy crops are the most likely to benefit from earth observation. It also highlights a few examples of biomass for electricity generation where available. Additional information on Earth observation parameters for agriculture can be found in the Task US-09-01a Agriculture SBA Prioritization Report. The Earth observation parameters of potential use for bioenergy applications are listed below in Table 6.

These Earth observation parameters may be applied to help identify appropriate locations and crop varieties for purpose-grown energy crops. These parameters may also be useful in monitoring and managing crop production and harvest, and identifying or quantifying anticipated biomass residues, such as from forests and agriculture. For example, the climate associated with high and low yield years in agriculture can also be characterized with many of the above-listed parameters.

Table 6. Earth Observation Parameters for Bioenergy Applications.

Parameter Type	Example Parameters
Vegetation and Soil Information	Normalized Difference Vegetation Index (NDVI)* Net Primary Productivity (NPP)* Evapotranspiration* Soil Moisture
Meteorological Parameters	Precipitation Wind speed Wind direction Relative humidity Air temperature Surface temperature
Characterization of Solar Resource	Direct normal irradiation (DNI)* Diffuse irradiation* Global horizontal irradiation (GHI)* Spectral distribution* Cloud cover (cloud index)
Land Information	Elevation/topography Land cover*

* Indicates parameters that are derived rather than measured directly. Note that some derived parameters listed here may rely upon the measured parameters also listed in this table.

Most of the documents discussed bioenergy observation needs in general terms, referring to the type of observation but without discussing coverage, resolution, accuracy, etc. Although none of the documents stated desired characteristics, several mentioned the currently used parameters:

- Spatial resolution for land cover was 80 meters in one document, but no note of adequacy was included (Elmore et al., 2008).
- Spatial resolution for net primary productivity (derived characteristic) was 1 degree of latitude/longitude (Elmore et al., 2008).
- The temporal resolution for net primary productivity was every eight days from the source, but the document used the data to create a single yearly average (Elmore et al., 2008).
- The documents examined did not address the accuracy or latency of parameters required for bioenergy. The Analyst recommends using any relevant information from the GEO Task US-09-01a Agriculture report to fill in absent details as appropriate.

4.5. Geothermal Energy

To be consistent with other sections of this report and as a necessary limitation of scope, the focus of this analysis is on electricity generation through geothermal energy, although geothermal energy can be used for other purposes such as direct heating of structures. The

Analyst, in conjunction with the Advisory Group, identified 14 documents that stated earth observation needs for geothermal energy, although most lacked details such as accuracy, spatial resolution, and timeliness. Because no documents directly addressed all of these details, the analysis is based upon a combination of the general statements indicated in those documents and details found regarding current observations and their adequacy from other sources.

Table 7. Earth Observation Parameters for Geothermal Applications.

Parameter Type	Example Parameters
Characterization of Geothermal Resource	Temperature of geothermal fluid (at depth) Fluid pressure Water Chemistry Rock Permeability
Land Information	Elevation/topography Land cover* Identification of areas of hot springs and heated surface water Surface displacement

* Indicates parameters that are derived rather than measured directly. Note that some derived parameters listed here may rely upon the measured parameters also listed in this table.

Several sources (e.g., Goldbrunner, 2005 and Ghomshei et al., 2005) indicated that the traditional method of determining potential geothermal resources is to locate areas where there is known surface hot water (such as hot springs) and drill wells to sample the water at depth, or to use existing wells from oil and other exploration or exploitation to measure the water's properties at depth. These sources as well as others (e.g., Saudi and Swarieh, 2005 and Dezhi et al., 2005) indicated the primary observations to characterize geothermal resources were the temperature at depth, fluid pressure, water chemistry, and rock permeability.

A recent government report indicated that ground displacement to an accuracy of less than 1 cm has been a high priority in the geothermal community, as it helps to identify areas of high strain that are likely to have geothermal resources (Aines et al., 2008). This report as well as others (e.g., Petty and Porro, 2007) emphasized that there are too few deep wells to fully characterize geothermal resources (especially at greater depths) and that sophisticated computer modeling using available data is used to fill in the gaps of empirical information.

One document noted that there is a strong correlation between the number of volcanoes in an area and the geothermal resources available (Stefansson, 2005). However, the document noted that the distribution of active volcanoes is already well known, indicating that the current observations may be adequate.

Another source indicated that there is an experimental method under development that can help to identify areas where geothermal resources exist and don't have obvious signs of activity without the need to drill wells (Kennedy and van Soest, 2007). This technique measures the ratio of helium isotopes ^{3}He and ^{4}He in surface waters as a proxy to thermal activity at depth. However, this method did not appear in other documents analyzed and documents validating this

finding were not located. Therefore, although it was considered, the identification of helium isotopes was not identified as a priority earth observation for the purposes of this report.

Although many of the statements of user needs for geothermal power were qualitative in nature, several documents did point out some specifics for spatial/temporal resolution, accuracy, latency, etc.:

- A recent government report indicated that ground displacement to an accuracy of less than 1cm has been a high priority in the geothermal community, as it helps to identify areas of high strain that are likely to have geothermal resources (Aines et al., 2008).
- One document noted that accurate assessment of local geothermal resources requires "several" wells to be drilled in the area, noting a need for multiple measurements but did not lay out a specific spatial resolution (Stefansson, 2005).
- One document listed geothermal resources in ranges of every 10^{o}C to every 50^{o}C (Petty and Porro, 2007). It did not specifically state a level of adequacy, but was able to characterize the resources, indicating that high levels of accuracy for the fluid at depth are not of substantial concern.
- Latency of parameters related to geothermal energy was not addressed in the documents examined.

5. Priority Observations

5.1. General description

Given the various forms of renewable energy that were examined in this analysis, the Analyst and the Advisory Group had to both incorporate the diversity of earth observation needs of different renewable energy types and focus on the highest overall priorities. In doing so, the Analyst produced two separate tables (Tables 9 and 10 below) that contain ranked priorities from different points of view. The Analyst later combined the two tables to create a final tiered priority list (Table 11 below), but at the advice of the Advisory Group retained the separate tables (Tables 9 and 10) as well to document how the final list was created.

5.2. Table of priority observations and characteristics

The first prioritization step focuses on identifying parameters that are required across multiple types of renewable energy. Table 8 combines the parameters listed for each renewable energy type in Tables 3 through 7 of this document. The check marks indicate that a given parameter is required for a given renewable energy type.

Table 8. Analysis of Parameters across All Renewable Energy Types.

Parameter Type	Parameter	RE Type					Total # of RE Types
		Solar	Wind	Geothermal	Hydropowe	Bioenergy	
Solar Resources	Direct normal irradiation (DNI) *	✓				✓	2
	Diffuse irradiation *	✓				✓	2
	Global horizontal irradiation (GHI) *	✓				✓	2
	Inclined plane radiation	✓					1
	Spectral distribution *	✓				✓	2
	Cloud cover (cloud index)	✓				✓	2
	Circumsolar ratio*	✓					1
Meteorological Parameters	Wind speed	✓	✓		✓	✓	**4**
	Wind direction	✓	✓			✓	**3**
	Relative humidity	✓	✓		✓	✓	**4**
	Air temperature	✓	✓		✓	✓	**4**
	Air pressure		✓		✓		2
	Surface Temperature	✓	✓		✓	✓	**4**
	Precipitation	✓	✓		✓	✓	**4**
Atmospheric Composition	Atmospheric ozone content *	✓					1
	Aerosol optical depth (AOD)*	✓					1
	Water vapor	✓					1
Land Parameters	Elevation/topography	✓	✓	✓	✓	✓	**5**
	Surface geology	✓			✓		2
	Land cover	✓	✓	✓	✓	✓	**5**
	Snow cover	✓			✓		2
	Identification of areas of heated surface water			✓			1
	Surface Displacement			✓			1
Offshore Environment	Wave height		✓				1
	Wave direction		✓				1
	Wave period		✓				1
	100-year significant wave		✓				1
	Current speed		✓				1
Vegetation, Soil, and Rock characteristics	Normalized Difference Vegetation Index (NDVI)					✓	1
	Net Primary Productivity (NPP)					✓	1
	Evapotranspiration					✓	1
	Soil Moisture					✓	1
	Rock Permeability			✓			1
Natural Hazards	Earthquakes frequency and intensity	✓					1
	Wildfire frequency and intensity	✓					1
Water	Availability of cooling water	✓					1
	Lake/Reservoir Height				✓		1
	Stream/river Flow				✓		1
	Water runoff				✓		1
Geologic Properties	Groundwater storage				✓		1
	Temperature at Depth			✓			1
	Chemistry at Depth			✓			1
	Fluid pressure at Depth			✓			1

* Indicates parameters that are derived rather than measured directly. Note that some derived parameters listed here may rely upon the measured parameters also listed in this table.

The parameters that rank the highest based on this analysis are those required for three (highlighted yellow) or four/five (highlighted green) renewable energy types. Thus, the highest ranking parameters are the meteorological parameters of wind speed, relative humidity, air temperature, surface temperature, and precipitation, and the land parameters of elevation/topography and land cover. The second highest ranking parameter is the meteorological parameter of wind direction. Table 9 shows the parameter characteristics of the highest ranked parameters (shaded green), and the second-highest ranked parameters (shaded yellow).

Table 9. Parameter Characteristics of High Ranking Cross-Cutting Parameters.

Parameter	Coverage/ Extent	Temporal resolution	Spatial resolution	Timeliness	Accuracy/ Precision
Precipitation	Global	Monthly	0.25 degrees x 0.25 degrees	Ranges from unimportant, to needed in advance (forecast)	Unknown
Elevation / topography	Global to site level	One-time measurement	1 km2 to m-scale (5-10 m vertical contours)	Not important	Unknown
Wind speed	Global land surface and marine coastal zone (5-50 km offshore)	Every 10 – 30 min	<1km2 to ~20 km2 horizontal, 10-200m+ vertical	Ranges from unimportant, to needed in advance (forecast)	Within 10% of annual average wind speed, or within 0.3 m/s
Relative humidity	(Dictated by meteorological models – see Weather SBA Report)				
Air temperature	(Dictated by meteorological models – see Weather SBA Report)				
Surface temperature	(Dictated by meteorological models – see Weather SBA Report)				
Land cover	Global land surface	Unknown (depends on timescale of land cover changes)	80m – 10 km	Unknown	Unknown
Wind direction	Global land surface and marine coastal zone (5-50 km offshore)	Every 10 – 30 min	<1km2 to ~20 km2 horizontal, 10-200m+ vertical	Ranges from unimportant, to needed in advance (forecast)	Within 3 degrees

5.3 Key Parameters for Priority Renewable Energy Types

The next prioritization step focuses on identifying parameters that are key for renewable energy types that are projected to be prominent according to the IEA World Energy Outlook (2008b). Figure 2 below (identical to Figure 1 earlier in this document) is from the World Energy Outlook and shows the increases from 2006 of each type of renewable energy.

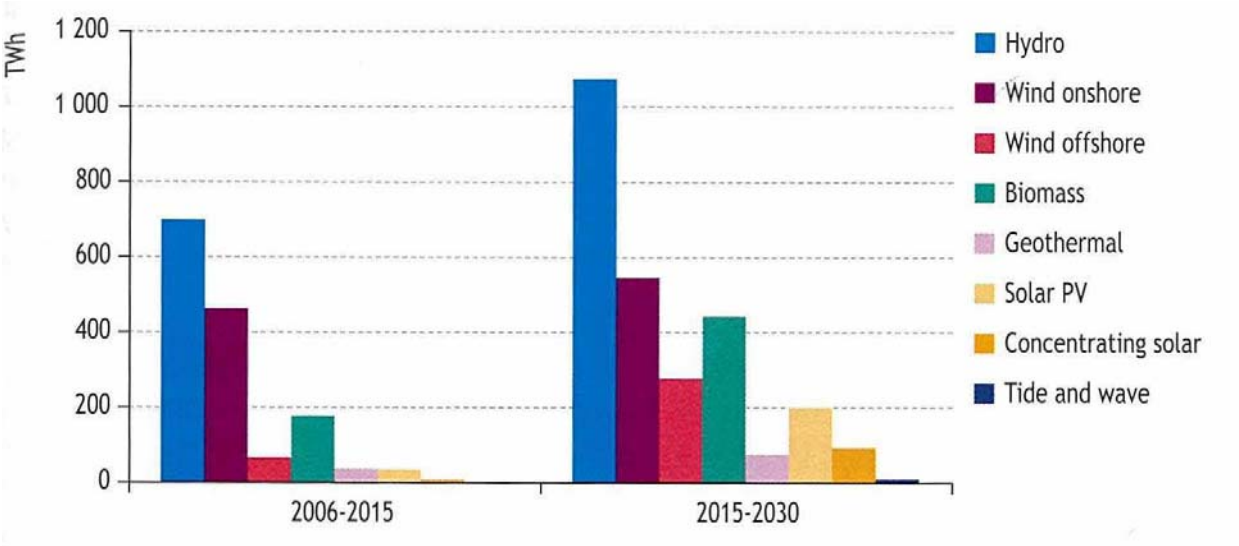

Figure 2. **Increase in World Electricity Generation from Renewable Energy in the World Energy Outlook 2008 Reference Scenario.**

Source: IEA 2008, Figure 7.3 (IEA, 2008b)

Based on analyses by the IEA (IEA, 2008b), in the medium term (2006-2015), hydropower will increase the most, followed by onshore wind, and distantly by biomass. In the long term (2015-2030), hydropower will also increase the most, followed by onshore wind, biomass, and offshore wind. Solar PV, and to a lesser extent concentrating solar power and geothermal, also are likely to become more widespread by 2030. Overall, the six "priority renewable energy types" in both time horizons, in order are:

1) Hydropower
2) Onshore (land-based) wind power
3) Biomass (bioenergy)
4) Offshore wind power
5) Solar PV and CSP
6) Geothermal.

Based on the literature discussed in previous sections and Advisory Group input, Table 10 lists the key parameters for each of these priority renewable energy types. In Table 10, the highest ranked renewable energy areas appear first, but the parameters within each renewable energy area are not ranked. As an example, the parameters required for hydropower are generally higher priority than the other types, given that hydropower was ranked by the IEA (2008b) as the highest renewable energy type. Additionally, Table 10 is meant to acknowledge that each renewable energy type may have distinct earth observation priorities, even though for this report the prioritization ultimately views the six priority renewable energy types as a whole.

Table 10. Key Parameters for Priority Renewable Energy Types.

Priority Renewable Energy Type	Top Parameters Required
Hydropower	Precipitation Reservoir/lake height Elevation Water runoff (modeled) Snow water equivalent
Onshore wind power	Wind speed Wind direction Wind shear Elevation Land cover
Bioenergy	Land cover Net primary productivity Precipitation Evapotranspiration Normalized Difference Vegetation Index (NDVI)
Offshore wind power	Wind speed Wind direction Wind shear Wave height
Solar PV and CSP	Global horizontal irradiation (GHI) Direct normal irradiation (DNI) Inclined plane radiation Air temperature Wind speed Wind direction Relative humidity
Geothermal	Water temperature at depth Fluid Pressure Rock Permeability Water Chemistry Land Cover

5.4 Advisory Group Refinement

The final prioritization step focuses on reconciling the observation priorities identified by the first two prioritization steps, and allowing for expert input from the Advisory Group to finalize the list. The Analyst requested assistance from all Advisory Group members on reconciling and prioritizing the Tables 9 and 10 to create a single list of prioritized parameters. Although the Analyst did receive feedback from Advisory Group members regarding many sections of the document, few of the Advisors suggested combining the two tables into a final priority list, as requested by the GEO UIC. In combining these tables, the Analyst concluded that the most appropriate way to represent key aspects of both of the previous lists was to examine which ones are the highest priorities on both lists and create a tiered listing. Table 11 below is the result of this analysis. Tier 1 represents those parameters appearing on both Table 9 as well as the highest priority renewable energy type: hydropower. Tier 2 includes those parameters which appear on

Table 9 and are also the second highest priority renewable energy type: onshore wind power. Tier 3 contains the remainder of the priorities mentioned in Table 9 (all of which appear in Table 10 as well). Finally, Tier 4 represents the remaining parameters from Table 10 which were not included in Table 9, and which are of substantially lower priority because they are not cross-cutting for multiple renewable energy types as those in the higher tiers are.

Table 11. Earth Observations for Energy SBA.

Tier	Parameter	Characteristics of the Observations Parameters				
		Coverage/Extent	Spatial	Temporal	Accuracy	Latency
Tier 1	Precipitation	Global	0.25 degrees x 0.25 degrees	Monthly	Unknown	Ranges from unimportant, to needed in advance (forecast)
Tier 1	Elevation / topography	Global to site level	1 km2 to m-scale (5-10 m vertical contours)	One-time measurement	Unknown	Not important
Tier 2	Wind speed	Global land surface and marine coastal zone (5-50 km offshore)	<1km2 to ~20 km2 horizontal, 10-200m+ vertical	Every 10 – 30 min	Within 10% of annual average wind speed, or within 0.3 m/s	Ranges from unimportant, to needed in advance (forecast)
Tier 2	Wind direction	Global land surface and marine coastal zone (5-50 km offshore)	<1km2 to ~20 km2 horizontal, 10-200m+ vertical	Every 10 – 30 min	Within 3 degrees	Ranges from unimportant, to needed in advance (forecast)
Tier 2	Land cover	Global land surface	80m – 10 km	Unknown (depends on timescale of land cover changes)	Unknown	Unknown

Table 11. (Continued).

Tier	Parameter	Characteristics of the Observations Parameters				
		Coverage/Extent	Spatial	Temporal	Accuracy	Latency
Tier 3	Relative humidity	(Dictated by meteorological models – see Weather SBA Report)				
Tier 3	Air temperature	(Dictated by meteorological models – see Weather SBA Report)				
Tier 3	Surface temperature	(Dictated by meteorological models – see Weather SBA Report)				
Tier 4	Reservoir / lake height	Unknown	350-580 m horizontal (current)	10-35 days (current)	3-10 cm RMS (current)	7-10 days (current)
Tier 4	Water runoff (modeled)	Unknown	Unknown	Unknown	Unknown	Unknown
Tier 4	Snow water equivalent	Unknown	7km x 7km (current)	Unknown	Unknown	Unknown
Tier 4	Wind shear	Unknown	Unknown	Unknown	Unknown	Unknown
Tier 4	Net primary productivity	Unknown	1 degree x 1 degree (current)	Every 8 days (current)	Unknown	Unknown
Tier 4	Evapo-transpiration	Unknown	Unknown	Unknown	Unknown	Unknown
Tier 4	Normalized Difference Vegetation Index (NDVI)	Unknown	Unknown	Unknown	Unknown	Unknown
Tier 4	Global Horizontal Irradiation (GHI)	Unknown	Unknown	15 minutes – 1 hour (current)	<< 5-20% rRMSE	Unknown

Table 11. (Continued).

Tier	Parameter	Characteristics of the Observations Parameters				
		Coverage/Extent	Spatial	Temporal	Accuracy	Latency
Tier 4	Direct Normal Irradiation (DNI)	Unknown	Unknown	Hourly to monthly (current)	<< 15-25% rRMSE	Unknown
Tier 4	Inclined plane radiation	Unknown	Unknown	Unknown	Unknown	Unknown
Tier 4	Water/fluid temperature at depth	Unknown	Unknown	Unknown	10^oC-50^oC (current)	Unknown
Tier 4	Fluid pressure	Unknown	Unknown	Unknown	Unknown	Unknown
Tier 4	Rock permeability	Unknown	Unknown	Unknown	Unknown	Unknown
Tier 4	Geologic water chemistry	Unknown	Unknown	Unknown	Unknown	Unknown

6. Additional Findings

Ocean Energy (including tidal energy and wave energy) was examined as part of this analysis. However, projections indicated that this type of energy is not likely to play a large role in renewable energy through at least 2030 (IEA, 2008b). Because of the limited role that ocean energy is likely to play through the next few decades, it ultimately was not included in the prioritization. This is not meant to diminish the potential growth and importance that ocean energy may have in the future, but rather to be an acknowledgement of the current status of the energy type as well as the projections for the next few decades, indicating that it is not among the highest priorities for earth observations in the immediate future.

Many documents discussed a request or desire for specific technology types rather than underlying observations. This included requests for a specific satellite technology or particular ground sensors. The Analyst, following the direction of the UIC, avoided the use of specific technologies or platforms in the prioritization. Instead, when a specific technology was referenced, the underlying observation(s) that the technology measures were substituted for the technology itself, while acknowledging how it was presented in the source. If it was not possible

to determine what observations were being referenced due to ambiguity or insufficient information, the technology reference was excluded from the analysis.

7. Analyst Comments and Recommendations

While not a parameter characteristic identified as part of the US-09-01a task, several documents and Advisory Group members noted that long-term consistency of Earth observations is important for planning a solar energy facility. For example, several documents noted that financing of renewable energy projects such as CSP is hindered by the high inter-annual variability of DNI. The timescale required varies by parameter and application. For CSP projects, at least 10 years of historical DNI is required, and 20 years of historical data is even better. However, for PV projects, several documents indicated that 3 to 5 years of historical GHI is sufficient, since variability from year to year is low.

The endowment of renewable energy resources varies by continent, region, country, and even sub-regions within a country. As such, parameters that support a specific type of renewable energy (e.g., solar) may be useful in one location and useless in another. Also, different Earth observation monitoring technologies lend themselves to different scales. Thus, an organization looking to invest in ground-based monitors would not be interested in a satellite-based technology option. Although a single set of Earth observation priorities will be identified by the above-outlined method, the complete analysis results in this document may help individual organizations match their monitoring resources with observation needs.

Given that this was the first time that this type of analysis has been performed, both for the Energy SBA as well as the other SBAs, the Analyst was instructed to provide feedback on the process and give recommendations for possible future analysis. In general, the Analyst agrees with the process as outlined by the UIC. Even though many of the members of the Advisory Group ultimately provided excellent feedback, there were instances where it was difficult to engage the group. The Analyst recommends an introduction of the task to come from GEO or other sponsors early on in future analysis. Given that the experts in the Advisory Group are likely to have many demands on their time, an official letter or other acknowledgement will help bring this task to a higher level of attention and hopefully provide more consistent and complete participation by the Advisory Group. Although there may be logistical issues and difficulty arranging a proper funding mechanism, another idea would be a small honorarium which would be awarded in consideration of sufficient involvement by the advisory group member throughout the process. This may be especially helpful in obtaining increased involvement from experts in developing countries.

Appendix A: Abbreviations

AOD	Aerosol optical depth
CNES	Centre National d'Etudes Spatiales (French Space Agency)
COP	Community of Practice
CSP	Concentrating solar power
DNI	Direct Normal Irradiance
EWEA	European Wind Energy Association
EOMD	Earth Observation Market Development
ESA	European Space Agency
GEO	Group on Earth Observations
GEOSS	Global Earth Observation System of Systems
GHI	Global horizontal irradiation
GRACE	Gravity Recovery and Climate Experiment
IEA	International Energy Agency
INPE	Instituto Nacional de Pesquisas Espaciais (Brazil)
LiDAR	Light Detection and Ranging
MW	Megawatt
NASA	National Aeronautics and Space Administration (USA)
NDVI	Normalized Difference Vegetation Index
NPP	Net Primary Productivity
NREL	National Renewable Energy Laboratory (USA)
PV	Photovoltaic
RMS	Root mean square
rRMS	Relative root mean square error
SAR	Synthetic Aperture Radar
SBA	Societal Benefit Area
SoDAR	Sonic Detection and Ranging
TERI	The Energy and Resources Institute (India)
TRMM	Tropical Rainfall Measuring Mission
UIC	User Interface Committee
UNEP	United Nations Environment Programme
USDA	United States Department of Agriculture

Appendix B: Bibliography

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